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The Quasicrystal Turns 20

It's been 20 years since researcher Dan Schechtman at the National Institute of Science and Technology discovered materials known as quasicrystals. Over those past two decades, the U.S. Department of Energy's Ames Laboratory has become an international leader in the study and development of these curious materials.

Since 1996, Ames Laboratory researchers have published about 100 papers related to quasicrystal research and have been invited speakers at numerous international conferences on the materials. In fact, Ames Lab hosted an international conference in 1996 and will be the host site again in 2005. In addition, the Lab hosts a steady stream of foreign researchers, participates in numerous international collaborations and provides large-scale quasicrystalline samples to research facilities and companies around the world. And the group's Web site (*www.quasi.iastate.edu*) is ranked as one of the most comprehensive anywhere.

Quasicrystals are metallic alloys, most of which contain 60 percent to 70 percent aluminum. Though they share characteristics with conventional crystals, they exhibit a very unusual atomic structure. Their uniqueness stems from the fact that they exhibit rotational symmetries, most commonly a five-fold symmetry that is not consistent with periodic structures.

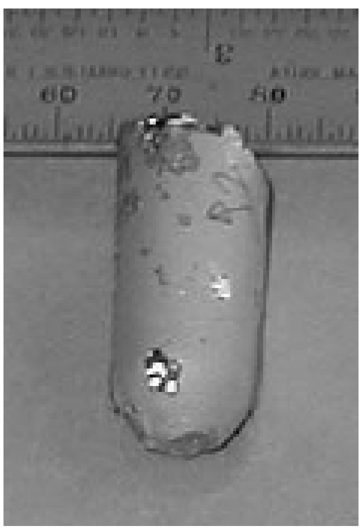
Shown above is Paul Canfield's version of the Ames Lab logo, using two decagonal and one icosahedral single-grain quasicrystals.

Known for being hard, relatively "non-stick," poor conductors of heat and resistant to chemical attack, quasicrystals are promising candidates for applications such as coatings, metal matrix components, hydrogen storage materials, thermal barriers, infrared sensors and other functions. Some applications already on the market include high-strength aluminum alloys, cookware, surgical tools and electric shavers, and quasicrystals are being studied for use as coatings for automotive parts.

Ames Lab's work on quasicrystals started when physicist Alan Goldman joined the research staff in 1988. Before coming to Ames, Goldman had *continued on next page*

established himself as an expert in the field, gaining recognition for his studies on the importance of “randomness” in stabilizing the structure of quasicrystals. At about that same time, thermodynamically stable phases were discovered by researchers in France and Japan, and the unique physical properties of the quasicrystals were first realized.

Goldman’s interest in quasicrystals rubbed off on a number of Ames Lab colleagues in the Metal and Ceramic Sciences (formerly Metallurgy and Ceramics) Program as well as Pat Thiel, director of the Materials Chemistry Program. As a surface chemist, Thiel was



The largest single grain of a cadmium-ytterbium ($Cd_{84}Yb_{16}$) quasicrystal with high phase purity synthesized using the Bridgman technique. Single grains approaching 1 cm^3 can be obtained by maintaining the melt during growth in a chemically benign tantalum crucible.

interested in the surface aspects, but realized that to truly understand quasicrystals requires knowledge of not only what takes place at the surface, but how the materials form. It also requires producing material to study.

To tackle the problem on multiple fronts, Thiel organized an interdisciplinary team consisting of chemists, physicists, chemical engineers, materials scientists and metallurgists to produce and study all aspects of the materials. Besides Thiel and Goldman, the team included, among others, Tom Lograsso and Paul Canfield who developed different methods for growing large-scale crystals to study. High-pressure gas atomization techniques developed by Iver Anderson were used to produce quasicrystalline powders, and Dan Sordelet learned to tune plasma spray techniques to apply a quasicrystal-rich coating that takes advantage of the material’s wear and corrosion resistance.

The Ames Lab team has made significant advances on all fronts. In surface studies, it was discovered that in quasicrystals consisting mostly of aluminum, the exposed surfaces are almost entirely made up of aluminum atoms in densely packed layers rather than having the composition of the bulk of the crystal’s material — bulk-terminated (lateral) structure. Under typical environmental conditions, the aluminum oxidizes, forming a thin, hard layer of aluminum oxide that contributes to the corrosion-resistance and low reactivity of the materials. In recognition of this work, the group received the DOE’s 1998 Materials Sciences Award for “Outstanding Scientific Accomplishment in Materials Chemistry.”

Since then, the group has developed a way to “clean” the surface of the material by damaging the surface and “regrowing” it from the bulk of the crystal of aluminum-paladium-manganese ($Al_{72}Pd_{19.5}Mn_{8.5}$). This technique shows that surface regrowth takes place in layers, forming “terraces” at three different levels and is quasicrystalline in nature.

These discoveries were enabled by the crystal-growth research of Lograsso’s group. Using Bridgeman and other techniques, Lograsso has grown single-grain aluminum-paladium-mangenese quasicrystals and aluminum-copper-iron quasicrystals. More recently, he

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> *–Pat Thiel*

synthesized the largest single grain of a cadmium-ytterbium ($Cd_{84}Yb_{16}$) quasicrystal.

Using flux growth, Canfield produced single-grain quasicrystalline rare earth-magnesium-zinc (R-Mg-Zn). Samples have also been prepared by consolidating quasicrystalline powders by hot isostatic pressing or sintering.

“We’ve become known as the source for large-scale crystals,” Thiel notes. “I remember presenting at a conference and putting up a slide showing one of the centimeter-scale, perfect crystals Paul had produced, and there was a collective gasp, then a mumur that passed through the crowd. I later found out they were saying, ‘Look at the scale!’ Most of these researchers had never seen a quasicrystal without the aid of a microscope … or even an electron microscope … and they could barely believe their eyes.”

Besides the wear- and corrosion-resistant coatings mentioned earlier, Ames Lab aluminum-based composites with quasicrystalline additives are more environmentally friendly because they can be completely recycled. Current strengthening additives, such as silicon carbide, can’t be readily separated from aluminum alloys, so these materials cannot be recycled.

Another development for use of quasicrystals is work by Valerie Sheares in the production of polymers containing quasicrystal particles. By adding quasicrystals to high temperature polymers, Sheares has produced a composite that is easily formed like a polymer, but with the wear resistance and low friction (non-abrasive qualities of quasicrystals.

One other indicator of the overall *continued on next page*

A single-grain holmium-magnesium-zinc quasicrystal grown by Paul Canfield and Ian Fisher from the ternary melt, compared in size to a U.S. penny. Ames Lab has led the field in growth of such large-scale crystals.

strength of the Ames Lab research effort was the spinoff of the "Science of Amorphous and Aperiodic Materials" area within the Metal and Ceramic Sciences Program. This newly defined research area is aimed at understanding (i) the correlation between short-range atomic order and the devitrification and deformation behavior in amorphous systems and (ii) the role of crystal chemistry (i.e., structure, bonding and lattice energies) in controlling the structural stability of aperiodic systems.

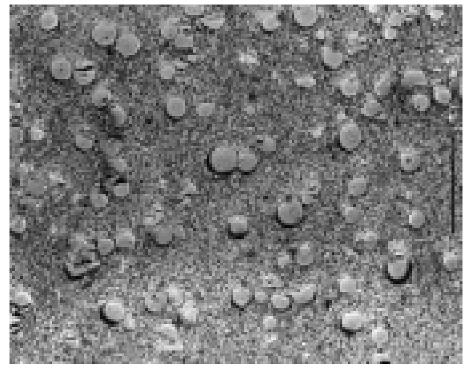
As for the future of quasicrystal research, Thiel is excited about the possibilities, particularly the promise shown with the formation of the Amorphous and Aperiodic Materials group.

"It will address the whole issue of clusters head-on," Thiel says, "and is exactly what was needed." Work in quasicrystalline thin films will help in understanding surface energies, and Thiel adds that Ames Lab is collaborating with Lawrence Berkley National Lab to delve into the atomic nature of the material's low-coefficient of friction.

Perhaps more importantly, the research has brought about a new vision and approach to finding answers to fundamental questions about the nature of materials.

"Quasicrystals have been a difficult problem to solve and have forced materials scientists and condensed matter physicists to work together and look at things differently," Thiel says. "The good thing is that we now have tools that we can use to go back and answer some of the easier, more basic questions. We need to move beyond quasicrystals and look at alloys with multiple characteristics and identify new phases." ■

~ Kerry Gibson



A micrograph shows quasicrystalline powders developed for use as wear-resistant coatings.